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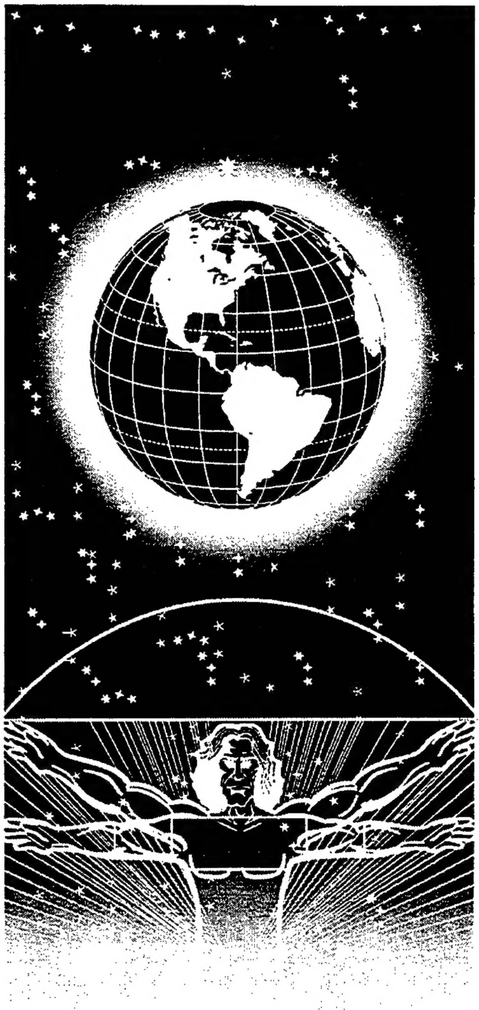

UNITED STATES AIR FORCE RESEARCH LABORATORY

TOPOGRAPHIC AND EVENT-RELATED POTENTIAL CORRELATES OF TASK TYPE AND TASK DIFFICULTY

Rodney A. Swain

LOGICON TECHNICAL SERVICES, INC.
P. O. BOX 317258
DAYTON OH 45431-7258

Glenn F. Wilson

HUMAN EFFECTIVENESS DIRECTORATE
CREW SYSTEM INTERFACE DIVISION
WRIGHT-PATTERSON AFB OH 45433-7022

Barbara Palmer

LOGICON TECHNICAL SERVICES, INC.
P. O. BOX 317258
DAYTON OH 45431-7258

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Human Effectiveness Directorate
Crew System Interface Division
2255 H Street
Wright-Patterson AFB OH 45433-7022

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

JOHN E. KENT, COL, USAF, BSC
Deputy Chief, Crew System Interface Division
Air Force Research Laboratory

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6. AUTHOR(S)
Rodney A. Swain*
Glenn F. Wilson**
Barbara Palmer*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
*Logicon Technical Services, Inc.
P. O. Box 317258
Dayton OH 45431-7258

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13. ABSTRACT *(Maximum 200 words)*

This experiment examined the topographical pattern of event-related potentials (ERPs) in three separate tasks whose solution primarily engaged different components of human information processing capabilities. The tasks were stimulus degradation, linguistic, and mathematical processing. In addition, the impact of differing task difficulty on characteristics of the evoked patterns was assessed. The results indicate that the pattern of electrical activity evoked by the tasks was quite similar in the first 200 ms following trial onset. The topography of later ERP components (200 ms post-trial onset) however, evidenced unique response patterns, suggesting that these components may serve as reliable indices of the type of cognitive processing being employed. Increasing task difficulty had little effect on the overall pattern of evoked response, but did selectively alter the amplitude and/or latency of components within particular tasks.

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PREFACE

This effort was conducted by the Human Interface Technology Branch (AFRL/HECP), Human Effectiveness Directorate (AFRL/HE) of the Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio. The project was completed under Work Unit 71841425, "Operator Workload Assessment." Logicon Technical Services, Inc. (LTSI), Dayton, Ohio, provided support under contract F41624-94-D-6000, Delivery Order 0004. Mr. Donald Monk was the Contract Monitor.

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INTRODUCTION

The search for reliable indices of mental effort have been extensive. One physiological measure which has received a great deal of attention is the event-related potential (ERP). ERPs are scalp-recorded measures of transient voltage fluctuations that are composed of separate but overlapping components which reflect the physical registration and sensory processing of external stimuli as well as higher level cognitive processing related to those same events. Because of this, it has been proposed that the ERP may serve as a valuable index of the cognitive effort necessary to perform a task (Humphrey & Kramer, 1994; Wilson & Eggemeier, 1992). Typically, experiments of this type involve the dual performance of a primary and secondary or probe task. ERPs may be recorded during either or both of the tasks. Generally speaking, as the cognitive effort needed to complete one of the tasks increases, there is a concomitant decline in the ERP recorded to the other task, suggesting that cognitive resources allotted to performance are finite and must be redistributed as task demands change (Wickens, Kramer, Vanasse & Donchin, 1983).

A substantial number of studies have suggested that the early components (processing negativity and N1-P2-N2 complex) of the ERP (less than 200 ms following the evoking stimulus onset) are exogenous and reflect the selection of physical properties of the stimulus. For example, the onset and duration of the processing negativity reflects the nature and difficulty of stimulus selection and its topography reflects the modality of stimulation (Gevins & Cutillo, 1986). The amplitude and latency of the N1 potential are affected by the subject's behavioral state and the properties of the stimulus and not by the informational content of the stimulus (Naatanen & Picton, 1987). Both the P1 and N1 peaks are probably generated in the sensory cortex and may be a function of feature encoding. The P2 is considered exogenous as well although its characteristics are not so dependent on stimulus modality. Although the P2 has traditionally been regarded as an index of sensory processing, a body of work indicates its involvement in cognitive processing (Papanicolaou & Johnstone, 1984). N2 peaks are seen when infrequent stimuli

are presented, whether or not the stimulus is task-relevant or attended. Its amplitude is inversely related to the frequency with which the deviant stimulus is presented.

Later components, especially the P3 (or P300), have been associated with such cognitive factors as selective attention, stimulus evaluation, updating, controlled processing, and task difficulty. The P3 component is thought to represent central information processing during task-related decision-making. Changes in P3 may result from increasingly difficult stimulus discrimination and categorization judgments, and variations in its amplitude and latency may provide a useful index of cognitive workload. In general, more difficult discriminations tend to produce smaller and later P3s (Hillyard & Kutas, 1983; Fitzgerald & Picton, 1983, 1984; Gevins & Cutillo, 1986). Larger memory loads and more difficult mental rotation tasks are also associated with smaller P3s, longer P3 latencies, and slower reaction times (Gomer *et al.*, 1976; Adams & Collins, 1978; Friedman *et al.*, 1981; Sergeant *et al.*, 1987; Wilson *et al.*, 1994; Mecklinger *et al.*, 1992).

Despite the fact that multiple components are generally observable in the ERP, many studies limit analysis to only one component. Also, most commonly, the characterization of a component is restricted to a set of midline electrodes. Seldom has the topographical distribution of a range of ERP components been described in studies of mental workload (but see Wilson *et al.*, 1994).

In the present study, we sought to characterize the topographical distribution, amplitude, and latency of brain electrical activity as seen in the event-related potential as a function of task type and task difficulty. Three disparate tasks (stimulus perception, linguistic processing, and mathematical processing) were selected on the basis that they tap different cognitive processes. Each task was presented in the visual domain and required a similar motor response. However, the mental processes that must intervene between the sensory and motor aspects of the task were quite different. In every case, the mental effort required to complete each task was manipulated to assess the impact of these variables on the electrical characteristics of the ERPs. Our goal was to describe the patterns of evoked brain activity to specific tasks and how these patterns are affected by increasing task

difficulty, and also to characterize the manner in which the patterns are the same or different for the three tasks.

METHODS

Subjects

Nine young adult males (M=23.8 years) participated and were paid for their involvement. The Edinburgh Handedness Inventory (Oldfield, 1971) indicated that eight of the nine subjects were right-handed and one was ambidextrous (M = 52.64 $\pm$ 11.16 SEM). The experimental protocol was approved by the Armstrong Laboratory Human Use Review Committee and informed consent was received from each subject.

Procedure

Subjects were seated in a dimly lit, electrically shielded, sound-attenuated chamber and faced a computer monitor positioned about 90 cm from their eyes. The monitor was situated outside the experimental chamber and was viewed through a window. The stimulus displays for all tasks consisted of white characters of about seven ft lamberts seen against a dark gray background. Subjects responded for all tasks with a button press using fingers of the right hand.

Subjects received five, 50-trial presentations of training for the linguistic processing and mathematics processing tasks and one training session for the stimulus degradation task. Following these sessions, performance and physiological data were gathered during one experimental session. All subjects received all values of each variable (three tasks X two levels of difficulty). Tasks were presented in blocks and the order of difficulty randomly varied within blocks. Subjects received each block twice in the experimental session.

Recording Procedure

Subjects were fitted with a nylon cap containing 20 tin electrodes (Electro-Cap International) positioned according to the International 10-20 system. FPZ served as ground and the remaining 19 electrodes were active recording sites. Two tin electrodes at the mastoids acted as reference. ERPs were recorded on a topographic mapping system (Bio-Logic Brain Atlas) and were averaged across stimulus presentations for each task (50 for math and linguistic, 80 for stimulus degradation). Brain potentials were notch-filtered at 60 Hz and band-pass filtered from 0.1 to 30 Hz. Amplifier gains were set at 20,000 and the system deleted data segments containing artifacts (defined as signals exceeding 95% of the analog to digital range). Amplified signals were digitized at 128 samples/second. Subjects were instructed to limit eyeblinks and mouth movements. Electrode impedances were 5 KOhms or less. Sampling was triggered by a computer 152 ms before the video-synchronized onset of each stimulus. Epoch durations were 2048 ms for the math and stimulus degradation tasks and 1024 ms for the linguistic tasks.

Task Descriptions

Stimulus degradation task

The stimulus degradation task was designed to differentially tax resources committed to early perceptual processing (Gaillard & Verduin, 1983). The subject viewed one of the numbers 2, 3, 4 or 5 in either a normal or a visually degraded condition. In the non-degraded condition, 36 dots composed the frame and 14 composed the digit. In the degraded condition, 26 dots were seen as the frame, 14 dots still composed the digit, and 10 dots were placed in the area around the digit and interfered with its perception. Dimensions of the frame around the digit were 3 cm wide by 4.5 cm high. The number itself was 1 cm wide by 2.5 cm high. The subject used a four-key response pad to indicate which of the four numbers was on the screen. Stimulus durations were 200 ms and the time between stimulus offset and the onset of the next number varied between 2800 and 3800 ms.

Linguistic processing task

This task used the simultaneous presentation of two letters under two instruction sets to assess the effects of differential task demands upon linguistic processing resources (Posner & Mitchell, 1967). The easier task required subjects to indicate if the two letters were physically the same or physically different. That is, AA required a "same" response, whereas Aa and AB required a "different" response. In the more difficult condition, subjects indicated whether the two letters were both vowels or consonants. Ae and BB would be correctly answered "same" and AC would be considered different. Matched and mismatched pairs were equiprobable. The displays at their largest (capital letters) were 1 cm by 1 cm. Under the easier condition, letters were on the screen for 1 sec or until the subject responded. The interval in which there were no stimuli on the screen was 1 sec as well. The difficult condition presented the letters for 1.5 sec or until a response was made, and there was 0.5 sec between the offset of the first stimulus and the onset of the next.

Mathematical processing task

The mathematical processing task was designed to place differential demands upon the information processing resources allocated to arithmetic reasoning (Shingledecker, 1984). The subject was required to view and respond to 50 equations. The subjects' task was to decide whether the solution to the equation was less than or greater than five and to respond appropriately via a response pad with the right index or middle fingers. Performance demands were manipulated by increasing the number of operands in the equation from one (low demand) to two (high demand). Arithmetic operations were limited to addition and subtraction. The stimulus dimensions for the longest equations were 1 cm high by 9 cm in length. Stimuli were on the screen for 4 sec or until the subject responded, whichever happened first, and there were 3 sec between the offset of the first stimulus and the onset of the subsequent stimulus.

Analysis

Waveform distortions of ERPs due to reference site selection are an inherent problem in many studies (Hjorth, 1975, 1979, 1980; Kooi *et al.*, 1971; Law *et al.*, 1993). Such recording artifacts can assume major significance when the primary goal of the study is to describe the distribution of the event-related electrical field. Therefore, in the present study, an essentially reference-free distribution of the brain potentials was computed using the source derivation method developed by Hjorth (1975, 1979, 1980). The source derivation applies a Laplacian operator to compute the relative distribution of potentials from radial electrodes surrounding the site of interest. Signal processing in this manner not only provides better localization of cortical foci but also attenuates slow wave superimposition of the ERP data. In the present study, electrodes at the edges of the scalp were corrected using their nearest neighbor electrodes and included in the analyses.

Grand averaged waves and topographical maps were evaluated for component and site selection. Latencies and amplitudes were determined via a peak-picking program (Brain Utilities, BioTech Interface Company). Values were then analyzed at each electrode site using analysis of variance (ANOVA; SAS software) with difficulty level as the main factor. Initial results indicated that yes/no responses did not differ significantly, nor did replications within the session, so data were combined on these factors.

For both levels of task difficulty for each of the three tasks, topographic maps were generated for baseline-adjusted ERPs. Grand-averaged Hjorth-derived ERP waveforms were visually inspected and components were identified for each of the three tasks. Since the Hjorth transformation tends to make the waveforms more spatially focused, using only selected electrode sites was deemed a conservative and appropriate choice. Components were identified as a function of their latency and the degree of activity at electrode sites within the component's time range.

RESULTS

Task Performance

A two-way ANOVA (Task X Difficulty with a repeated measure on both factors) of the mean reaction times indicated that there were significant main effects for Task ($F(2,16)=36.03$, $p=.0001$) and Difficulty ($F(1,8)=103.17$, $p=.0001$) as well as a significant interaction between the 2 factors ($F(2,16)=38.47$, $p=.0001$). Post hoc analyses indicated that the mean reaction time was significantly longer for the high demand condition than for

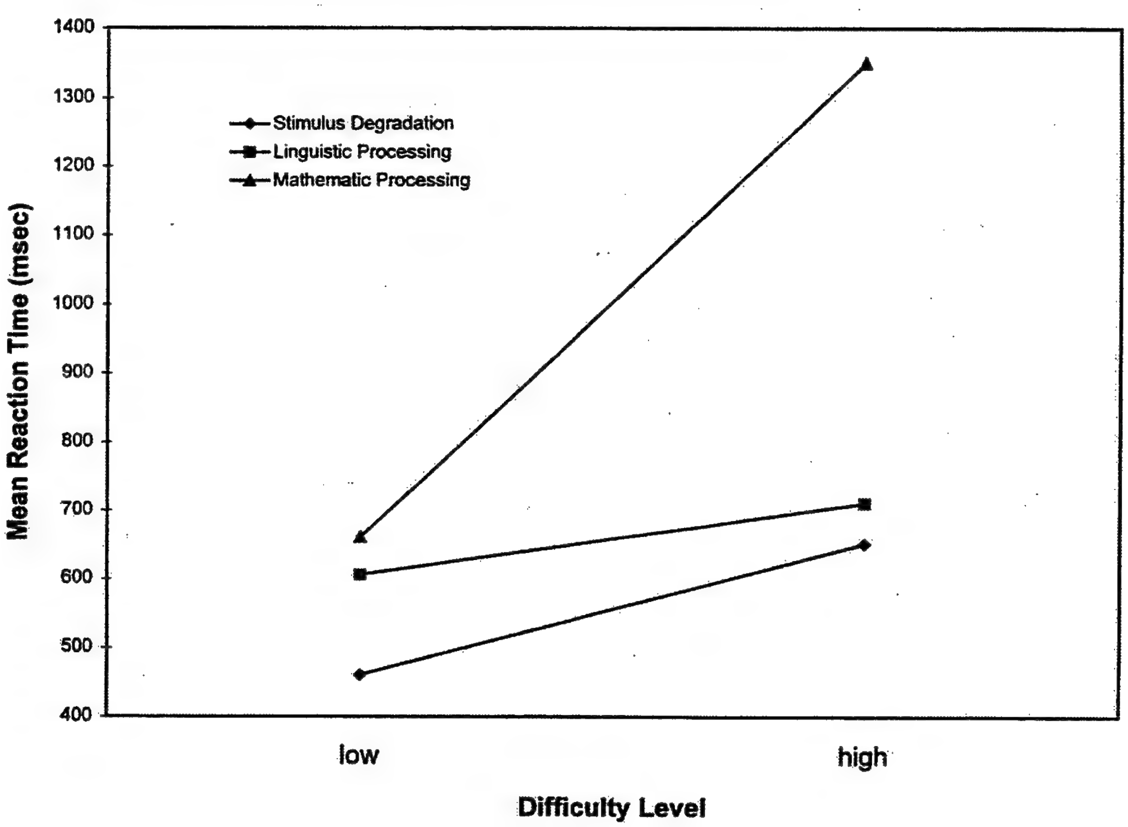

Figure 1. Mean reaction times for the two difficulty levels of the three tasks; stimulus degradation, linguistic processing, and mathematic processing.

the low for all tasks (all ps =.0001). Additional analyses (all ps < .01) indicated that reaction times were fastest for the linguistic task in the low difficulty condition and slowest for the math task in the high difficulty condition, see Figure 1. Furthermore, the magnitude of change in speed between the low and high difficulty conditions was greatest for the math task.

General Features of ERPs and Topographical Maps

Grand mean ERPs for the Pz electrode are presented in Figure 2. The ERPs from each of the three tasks are similar in waveform with a sharp positive peak around 100 ms followed by a trough at around 200 ms and a broader positive component with a peak latency at approximately 500 ms. In all three cases, the ERPs to the low and high task difficulty stimuli are quite similar until the second positive component where they deviate from one another. The return to baseline is longer for the high difficulty ERD in all three

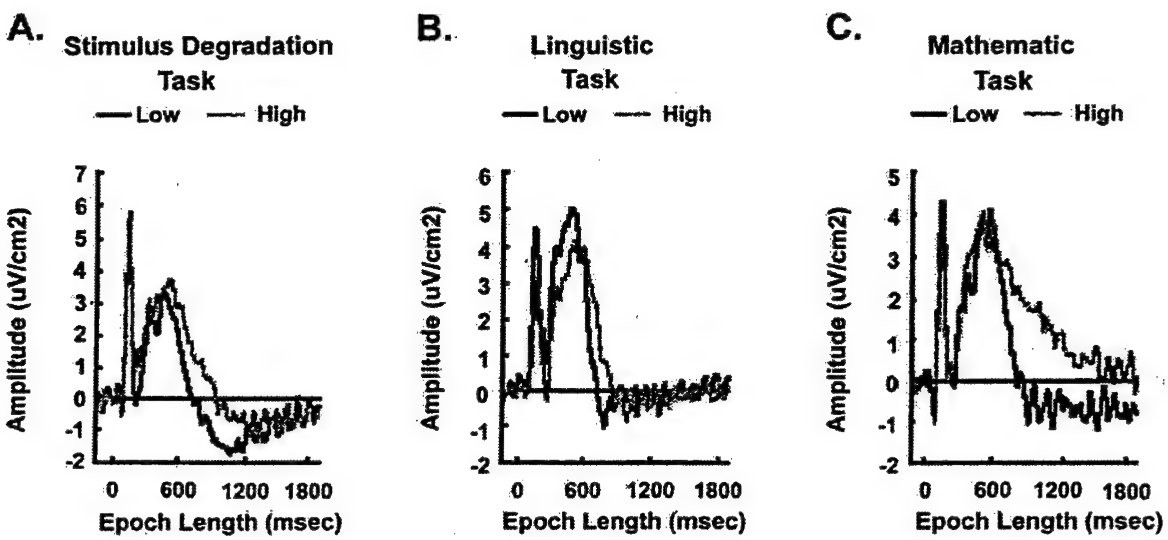

Figure 2. Grand mean ERPs across all subjects from electrode site Pz for the low and high conditions for each of the three tasks.

cases shown in the figure. The slower return to baseline in the ERPs to the high difficulty conditions is correlated with the longer RTs in those conditions.

Visual inspection of the grand average topographical maps for each task revealed a remarkable degree of similarity in the pattern of activity among the tasks (Figures 3, 5 and 7). For the linguistic and mathematical processing tasks, peak activity was noted over parietal and central sites. Maps of the stimulus degradation task showed a similar but somewhat delayed pattern. Beginning with time points greater than 96 ms from stimulus onset, the maps indicate that a large positive potential was localized over parietal regions, generally with the largest activity confined to the PZ site. As time progressed, this activity was observed to extend to more central sites, particularly C4 in the right hemisphere. Comparisons of workload conditions indicated that this pattern of activity was present in both the low and high demand conditions in all of the tasks, but that the transition from parietal to central foci was delayed and of smaller amplitude over CZ during the difficult conditions in both the linguistic and mathematical processing tasks (see Figures 5 and 7). The opposite pattern was observed with the stimulus degradation task. The transition of activity from parietal to central sites occurred earlier in the difficult task condition (see Figure 3).

Specific Task-Related Features of the ERPs

Stimulus Degradation Task

Grand average topographical maps of the low difficulty condition revealed broad spread electrical activity on the scalp associated with performance of the task, Figure 3. Visual inspection of the event-related potential revealed discriminable components in the 64-184, 184-336, and 336-528 ms time windows from stimulus onset. Signals in the earliest window, component I, were both positive and negative. Based on signal amplitude and quality, the positive potentials recorded at sites C3, CZ, C4, P3, PZ, and P4 and the negative potentials recorded at sites O1 and O2 were selected for statistical analyses (See Figure 4). A series of one-way analyses of variance (ANOVAs) for each electrode site

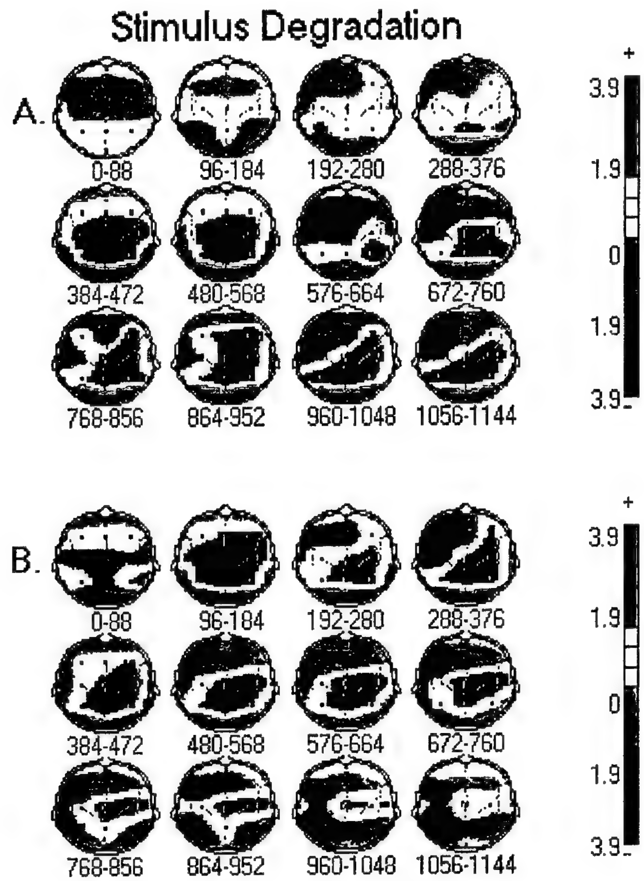

Figure 3. Mean topographical maps detailing the "flow" of current across the scalp during performance of the stimulus degradation task. A) Low difficulty undegraded condition. B) High difficulty degraded condition. Each map represents the activity for the time range specified below each map in milliseconds. The amplitude scale in uV/cm^2 is shown at the right.

using "Difficulty" as the repeated measures factor failed to find any statistical differences in amplitude or latency for signals recorded at these sites.

In the time window from 184 to 336 ms, component II, after stimulus onset, a positive peak was noted consistently across subjects at the T6 site and also across the occipital sites (O1 and O2). The T6 component did not differ significantly in either

amplitude or latency across workload levels. The polarity of the signal at the occipital sites reversed in the high demand level. This reversal was statistically significant for both the O1 and O2 electrodes ($\underline{F}(1,5)=26.33$, $\underline{p}=.0037$ and $\underline{F}(1,5)=12.42$, $\underline{p}=.0168$ respectively). Analysis of latency changes across the difficulty levels indicated that as the task became more difficult, the time to peak increased for both the O1 and O2 sites.

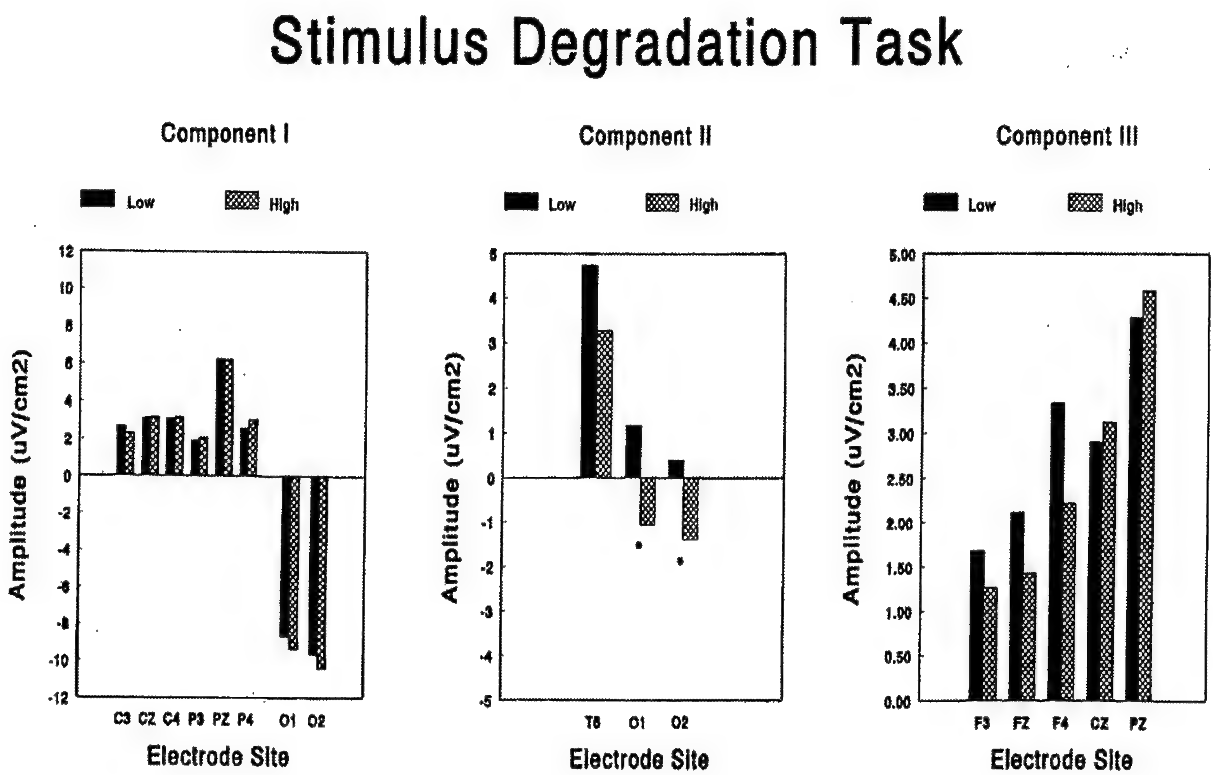

Figure 4. Grand mean amplitudes for the stimulus degradation task for the three components that were identified. Low and high difficulty means are shown for the selected electrode sites with those exhibiting statistically significant differences indicated with a dot above or below bars.

For the third component, signals were selected for analyses at F3, FZ, F4, CZ, and PZ. Neither amplitude or latency differed across difficulty levels at these sites.

Linguistics Processing Task

For this task a similar pattern to that observed in the stimulus degradation task was observed, grand average topographical maps of the ERP indicated that task-related activity

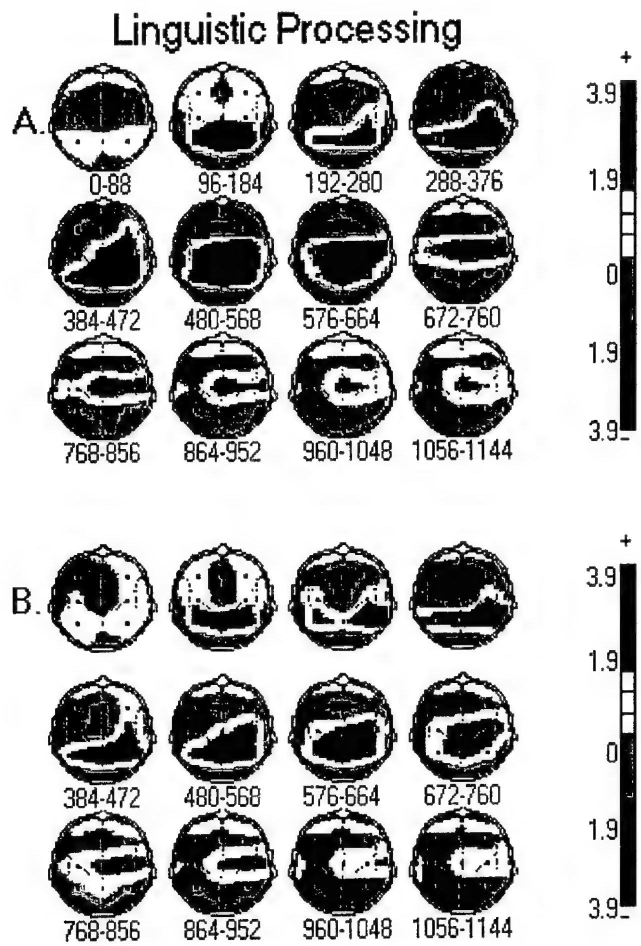

Figure 5. Group average topographical maps detailing the activity across the scalp during performance of the linguistic processing task. A) Low difficulty condition. B) High difficulty condition. The time range in milliseconds of each map is shown below maps. The amplitude scale in uV/cm^2 is shown at the right.

was broadly represented across the scalp (Figure 5). The ERP displayed at least four components, both negative and positive, with each lasting on the average several hundred milliseconds and located over relatively discrete electrode sites (Figure 6). Early in the trial (<250 ms from trial onset), a positive component (component I) was found to overlie parietal sites with the largest response occurring at PZ. The peak amplitude and latency for sites P3, PZ, and P4 were determined. Peak amplitude at all three sites declined as difficulty increased. However, a one-way ANOVA (for each site) with "Difficulty" as the repeated measures factor indicated that only the amplitude of the component at PZ could

Linguistic Task

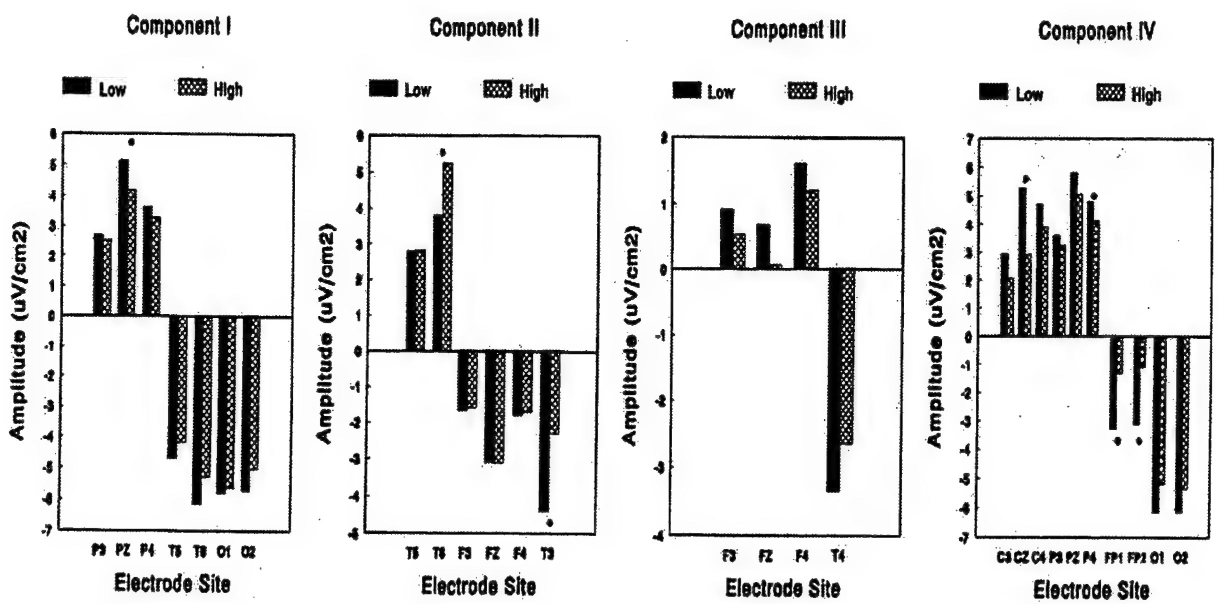

Figure 6. Component amplitudes for the group data representing the linguistic processing task ERPs. Amplitudes for the low and high difficulty conditions are shown for the four components at the selected sites. Significant differences between low and high amplitudes are designated by a dot above or below bars.

be used to successfully discriminate between the easy and difficult levels of the task ($F(1,8)=6.20$, $p=.0375$), declining on average 18.6% from the easy to difficult levels of the task. No significant differences in latency (peak range = 148-177) were noted across difficulty levels. A negative component over temporal and occipital regions was also discriminated. Sites T5, T6, O1, and O2 were selected for further analyses by ANOVA but no significant amplitude or latency differences were found across Difficulty levels.

A second component (component II) was observed over frontal and temporal sites between 295 and 350 ms after trial onset. Positive peaks were selected for further analyses over sites T5 and T6. ERP amplitude at T5 remained stable from the low to high workload conditions but increased by 27.5% at site T6. The latency of the ERP declined by approximately 7% at both sites as difficulty increased. ANOVA indicated that for the positive sites, the amplitude increase at T6 was marginally significant ($F(1,8)=5.21$, $p=.052$). The latency of the component, however, declined significantly across task difficulty (mean decline = 22.66 ms; $F(1,8)=6.84$, $p=.0309$). No other significant differences were noted.

Negative peaks were likewise chosen over sites F3, FZ, F4, and T3. Both amplitude and latency at all of the frontal sites remained stable. By contrast, the amplitude of the component at T3 decreased by approximately 47.5% from the low to high conditions ($F(1,8)=15.66$, $p=.0042$). The latency of this component also declined (5.34%). This decrement, however, was not significant.

For component III (peak range = 272 - 512 ms), positive peaks were noted at F3, FZ, and F4 and a negative peak was observed at T4. For all sites, component amplitude decreased and latency increased from the low to high workload condition. None of these differences were significant however.

Component IV was a broad potential with positive peaks located centrally and parietally. Negative peaks were located over both the occipital and frontal poles. Amplitude declined at all sites but was significant at only the CZ, P4, and FP1 and FP2 sites ($F(1,8)=21.81$, $p=.0016$, $F(1,8)=9.21$, $p=.0162$, $F(1,8)=7.39$, $p=.0263$, $F(1,8)=7.34$,

$\underline{p}$=.0267 respectively). Latency increased significantly at the PZ site only ($\underline{F}(1,8)=15.67$, $\underline{p}$=.0042).

Mathematical Processing Task

Between 64 and 184 ms, positive potentials were noted at all central and parietal sites, component I (Figure 8). Negative potentials were observed at the most ventral temporal sites and across the occipital region. Significant amplitude workload effects

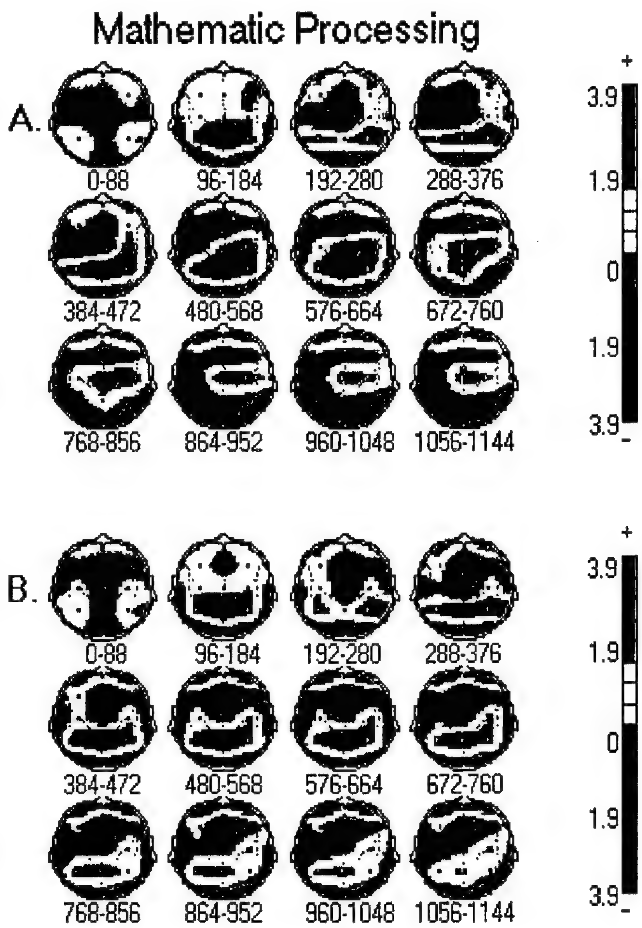

Figure 7. Mean topographical maps of scalp recorded activity showing the pattern of activation during the mathematical processing task. A) Low difficulty condition in which cognitive processing involved only one operand. B) High difficulty condition involving two operands. The amplitude scale in uV/cm2 is shown at the right.

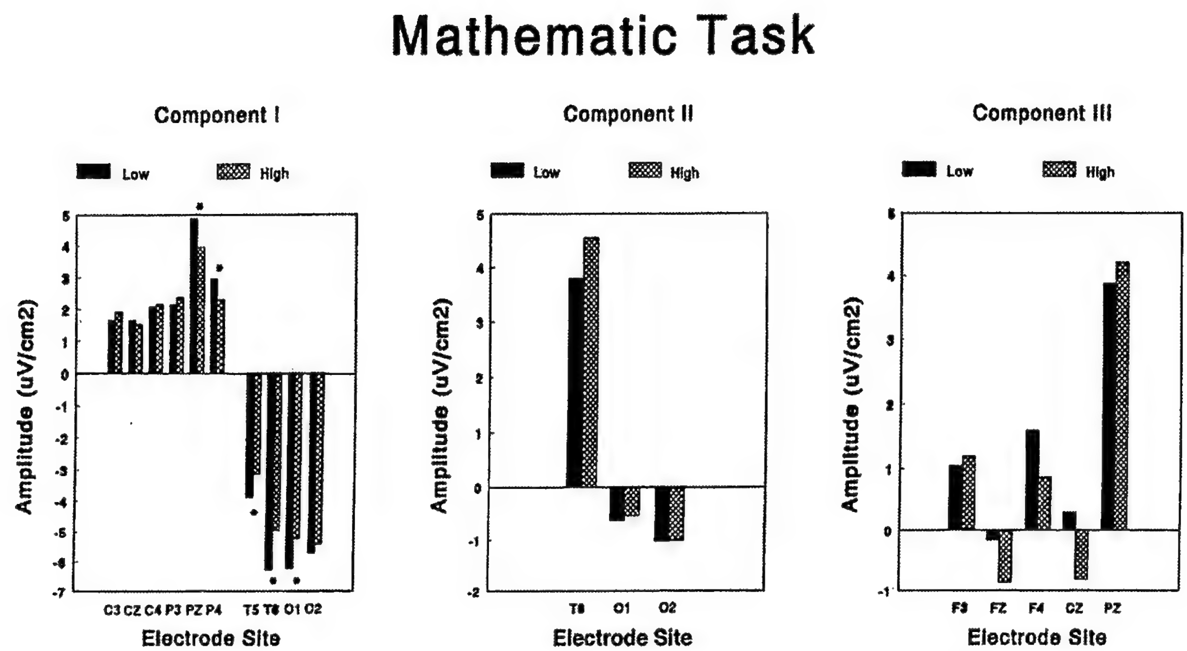

Figure 8. Grand mean component amplitudes for the three ERP components for the mathematic task. Significant differences between low and high difficulty conditions at the selected electrode sites are indicated by a dot above or below bars.

were observed at PZ and P4 (positive sites; $F(1,8)=10.64$, $p=.0115$ and $F(1,8)=8.67$, $p=.0186$ respectively) as well as at T5, T6, and O1 (negative sites; $F(1,8)=5.54$, $p=.0464$, $F(1,8)=16.35$, $p=.0037$, and ($F(1,8)=5.48$, $p=.0474$ respectively). No differences in latency were noted.

A second component (184-336 ms) was observed over temporal and occipital sites between 184 and 336 ms after stimulus onset. None of these sites showed any differences in amplitude or latency across difficulty levels.

A third component (336-448 ms) was seen at frontal sites and along the midline (F3, FZ, F4, CZ, and PZ). The only significant workload effect was a latency decrement at

the CZ site ($\underline{F}(1,8)=7.54$, $\underline{p}=.0252$). The average magnitude of the decrement in peak latency in the difficult condition was 28 ms.

DISCUSSION

At first glance, the results of this study would seem to indicate that disparate tasks produce similar patterns of brain activation. The series of time-lapse maps (Figures 3, 5, and 7) show patterns of activity that course across the scalp in similar ways. Further, ERP analyses also indicated that the tasks shared a remarkable degree of similarity (at least in early and middle latency components). Components I and II in all three tasks involved approximately the same sites. Common positive sites for component I included P3, PZ, and P4. Common negative sites for component I were O1 and O2. For component II, a positive component at T6 was common for all three tasks. This is perhaps not surprising in that the initial processing of all three tasks was in the visual domain. In-depth analyses indicated, however, that task-specific activity did present itself, especially in the later components.

Stimulus Degradation Task

In response to presentation of various letters under normal and degraded conditions, Lorist *et al.* (1994) reported the presence of a P3 to both conditions. While the amplitude of this component was very susceptible to mental fatigue, they failed to find differences between the intact and degraded conditions. However, in our study, we did find an earlier positive component, peaking between 184 and 336 ms, that diminished as the stimuli became degraded. This decrement in ERP amplitude was observable across both of the occipital sites.

Kok *et al.* (1985) also reported the presence of a late positive component (P630) and slow wave, both of which diminished in amplitude as the discernability of the letters decreased. Kok and colleagues only examined frontal, central, and parietal sites. In

contrast, we failed to find any significant changes in the late components elicited by our task.

Linguistic Processing Task

In the first 250 ms of the trial, both positive and negative potentials, perhaps reflecting cortical sources and sinks, were observed to overlie distinct regions of the scalp and underlying cortex. Positive ERPs were centered primarily over the P3-PZ-P4 region of parietal cortex while negative ERPs were localized over posterolateral portions of temporal and occipital cortices and midline frontal regions. ERPs of this type (occurring well before execution of the behavioral response) and within the time range generally associated with the N1-P2-N2 complex have been most often attributed to active processing of stimulus features (Naatanen & Picton, 1987). Papanicolaou and Johnstone (1984) have proposed, however, that at least one of these components, the P2, may reflect to some degree processing of the eliciting stimuli for informational content. Our own results are consistent with that hypothesis. The positive ERP over PZ decreased 18.6% in amplitude when the subjects had to decide whether the letters were both vowels or consonants regardless of the letters' physical features.

Our results also suggest that the distribution of the various components of the N1-P2-N2 complex may be used to discriminate whether the processing indicated by the ERP is of physical or semantic features. In our task, there was little variance in the physical features of the easy and difficult conditions of the task. It can be hypothesized that any ERP that indexes physical feature encoding would remain relativity unchanged in the two levels of our task. We found that the negative potentials over temporal and occipital sites did not vary in either amplitude or in latency suggesting that these waveforms index the sensory processing of the letters. By contrast, the positive potential at PZ changed quite dramatically when the task demanded semantic processing. A similar view, at least for one component of the N1-P2-N2 complex, has been espoused by Ritter *et al.* (1983). In their study they found that the scalp distribution of the N2 is different for physical and semantic

discriminations: the N2 elicited by the physical features of stimulation is located primarily over lateral recording sites while the N2 evoked by semantic discrimination occurs over more central sites.

Other ERP components which appeared to reflect the increased difficulty inherent in the semantic processing of the letters included a negative potential (N3) over temporal regions and broad slow negative going waves that were centered over central and parietal regions as well as the frontal poles. Ruchkin *et al.* (1988) propose that slow wave activity in the ERP can be broadly categorized as activity reflecting either perceptual or conceptual operations. They suggest that positive slow waves are typically associated with perceptual operations while those of negative polarity (like those currently under discussion) are more often associated with conceptual operations and that the scalp localization of the waves is dependent on the nature of the task (e.g., semantic vs. mathematical reasoning).

Mathematical Processing Task

Significant ERP workload effects were noted early in the mathematical processing task (<184 ms). Decrements in ERP amplitude were noted in the positive potentials over sites PZ and P4 and in the negative potentials over T5, T6, and O1. These results strongly indicate that discrimination of workload effects in the mathematical domain may be secured by examination of early components at tempero-parietal sites.

Late positive activity in mathematics tasks has been widely described over the tempero-centro-parietal and frontal sites (Inouye *et al.*, 1993; Pauli, Lutzenberger *et al.*, 1996; Pauli *et al.*, 1994; Roland & Friberg, 1985). Pauli and colleagues (1994) have indicated that the activity associated with the frontal sites primarily reflects arithmetic calculation and that this activity decreases with repeated practice as the subject acquires the ability to retrieve the answers directly from memory stores rather than needing to perform the calculations. In their most recent report (Pauli *et al.*, 1996), in which they extensively overtrained subjects on certain data sets but introduce a few rare calculations, they report that changes in frontal activity may represent a more general process of learning how to perform the task rather than pertaining to specific calculations. According to Pauli et. al,

activity over tempero-centro-parietal sites remains constant with practice and represents direct retrieval of arithmetic answers from memory stores.

As in the experiments referred to above, perhaps the most prominent feature of the topographical ERPs recorded during our task was the presence of two positive waves that were distributed over the parietal, central and temporal scalp. The earliest of these waves (peaking between 184 and 336 ms from trial onset) was recorded from temporal and occipital sites and showed no significant changes in either amplitude or latency across difficulty levels. This component is consistent in latency and form to the tempero-centro-parietal components described by Pauli et. al who assert that they reflect retrieval of answers from memory stores rather than calculation and are insensitive to problem set size.

The later waves (336-448 ms from trial onset) recorded over frontal, central and parietal sites showed no changes in amplitude but a significant decline in peak latency at the CZ site only. According to Pauli *et al.* (1996), activity at these sites can be thought to index acquisition of the general concepts associated with performing mental arithmetic and that activity declines with repeated practice because even the presentation of novel problem sets does not necessitate acquisition of new concepts. Since we did not record neural activity during practice sessions (our subjects were performing at asymptote), we can neither confirm nor refute their claim concerning amplitude decrements of this component with practice. However, our data do support Pauli's contention that this component is insensitive to problem set size and may reflect a general adaptational process.

CONCLUSION

The results of this study confirm the utility of topographical mapping in the assessment of cognitive workload effects. For each of the tasks, ERPs were observed at off-midline sites and quite often it was these off-midline sites that showed significant workload effects. Furthermore, the results indicate that while these very different tasks elicit activation at many common sites, each task is associated with unique workload

effects (at specific sites and for specific components of the ERPs) that make discrimination of the tasks possible. For example, our data indicate that the earlier ERP components (< 200 ms) evoked by all of the tasks were localized to similar sites. These components most likely reflect visual sensory processing of the task stimuli as this was the one trait which all of the tasks held in common. As such, these earlier components cannot be used to reliably indicate the type of task in which the subject was engaged. The topography of later components was distinct however, suggesting that identification of these potentials might be used for task classification. For example, the stimulus degradation task evoked activity over occipital sites (184 - 336 ms) that was unique to that task (these same sites were also sensitive to workload). Linguistic processing activated sites in parietal and central regions that were unique to that task. Finally, mathematical processing evoked early activity within parietal, occipital and temporal sites that was unique to that task.

REFERENCES

Adams, N., & Collins, G.I. (1978). Late components of the visual evoked potential to search in short-term memory. Electroencephalography and clinical Neurophysiology, 44: 147-156.

Fitzgerald, P., & Picton, T.W. (1983). Event-related potentials recorded during the discrimination of improbable stimuli. Biological Psychology, 17: 241-276.

Fitzgerald, P.G., & Picton, T.W. (1984). The effects of probability and discriminability on the evoked potentials to unpredictable stimuli. In: R. Karrer, J. Cohen, & P. Tueting (Eds.), Brain and Information: Event-related Potentials. New York, NY: The New York Academy of Sciences.

Friedman, D., Vaughan, H.G.J.R., & Erlenmeyer-Kimling, L. (1981). Multiple late positive potentials in two visual discrimination tasks. Psychophysiology, 18: 635-649.

Gaillard, A.W.K. and Verduin, C.J. (1983). The combined effects of an antihistamine and pseudoephedrine on human performance. Journal of Drug Research, 8, 1929-1935.

Gevins, A.S., & Cutillo, B.A. (1986). Signals of cognition. In: F.H. Lopes da Silva, W.S. van Leeuwen, & A. Remond (Eds.), Handbook of Electroencephalography and Clinical Neurophysiology: Clinical Applications of Computer Analysis of EEG and Other Neurophysiological Signals. New York: Elsevier.

Gomer, F.E., Spicuzza, R.L., & O'Donnell, R.D. (1976). Evoked potential correlates of visual item recognition during memory-scanning tasks. Physiological Psychology, 4: 61-65.

Hart, S.G. (1987). Research papers and publications (1981-1987): Workload Research Program. NASA Technical Memorandum 100016.

Hillyard, S.A., & Kutas, M. (1983). Electrophysiology of cognitive processing. Annual Review of Psychology, 34: 33-61.

Hjorth, B. (1975). An on-line transformation of EEG scalp potentials into orthogonal source derivations. Electroencephalography and clinical Neurophysiology, 39: 526-530.

Hjorth, B. (1979). Multichannel EEG preprocessing: Analogue matrix operations in the study of local effects. Pharmakopsychiatrie Neuro-Psychopharakologie, 12: 111-118.

Hjorth, B. (1980). Source derivation simplifies topographical EEG interpretation. American. Journal of EEG Technology, 20: 121-132.

Humphrey, D.G., & Kramer, A.F. (1994). Toward a psychophysiological assessment of dynamic changes in mental workload. Human Factors, 36: 3-26.

Inouye, T., Shinosaki, K., Iyama, A., & Matsumoto, Y. (1993). Localization of activated areas and directional EEG patterns during mental arithmetic. Electroencephalography and clinical Neurophysiology, 86: 224-230.

Kok, A., van de Vijver, F.R., & Rooijakkers, J.A.J. (1985). Effects of visual field, stimulus degradation, and level of practice on event-related potentials of the brain. Psychophysiology, 22: 707-717.

Kooi, K.A., Tipton, A.C., & Marshall, R.E. (1971). Polarities and field configurations of the vertex components of the human auditory evoked response: A reinterpretation. Electroencephalography and clinical Neurophysiology, 31: 166-169.

Law, S.K., Rohrbaugh, J.W., Adams, C.M., & Eckardt, M.J. (1993). Improving spatial and temporal resolution in evoked EEG responses using surface Laplacians. Electroencephalography and clinical Neurophysiology, 88: 309-322.

Lorist, M.M., Snel, J., & Kok, A. (1994). Influence of caffeine on information processing stages in well rested and fatigued subjects. Psychopharmacology, 113: 411-421.

Mecklinger, A., Kramer, A.F., & Strayer, D.L. (1992). Event related potentials and EEG components in a semantic memory search task. Psychophysiology, 29: 104-119.

Naatanen, R., & Picton, T. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. Psychophysiology, 24: 375-425.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia, 9: 97-113.

Papanicolaou, A., & Johnstone, J. (1984). Probe evoked potentials: Theory, method and application. International Journal of Neuroscience, 24: 107-131.

Pauli, P., Lutzenberger, W., Birbaumer, N., Rickard, T.C., & Bourne, Jr., L.E. (1996). Neurophysiological correlates of mental arithmetic. Psychophysiology, 33: 522-529.

Pauli, P., Lutzenberger, W., Rau, H., Birbaumer, N., Rickard, T.C., Yarmoush, R.A., & Bourne, Jr., L.E. (1994). Brain potentials during mental arithmetic: Effects of extensive practice and problem difficulty. Cognitive Brain Research, 2: 21-29.

Posner, M.I. and Mitchell, R. F. (1967). Chronometric Analysis of Classification, Psychological Review., 74: 392-409.

Ritter, W., Simson, R., & Vaughan, H.G., Jr. (1983). Event-related potential correlates of two stages of information processing in physical and semantic discrimination tasks. Psychophysiology, 20: 168-179.

Roland, P.E., & Friberg, L. (1985). Localization of cortical areas activated by thinking. Journal of Neurophysiology, 53: 1219-1243.

Ruchkin, D.S., Johnson, R. Jr., Mahaffey, D., & Sutton, S. (1988). Toward a functional categorization of slow waves. Psychophysiology, 25: 339-353.

Sergeant, J., Geuze, R., & van Winsum, W. (1987). Event-related desynchronization and the P300. Psychophysiology, 24: 272-277.

Shingledecker, C.A. (1984). Task battery for applied human performance assessment research. Technical Memorandum AAMRL-TR-84-662202F, AMD, AFSC, Wright Patterson Air Force Base, Ohio.

Wickens, C. D., Kramer, A. F., Vanasse, L. & Donchin, E. 1983. The performance of concurrent tasks: A psychophysiological analysis of the reciprocity of information processing resources, Science, 221, 1080-1082.

Wilson, G.F., & Eggemeier, F.T. (1992). Psychophysiological assessment of workload in multi-task environments. In: D. Damos (Ed.), Multiple Task Performance: Selected Topics. London: Taylor and Francis.

Wilson, G.F., Swain, R.A., & Davis, I. (1994). Topographical analysis of event-related potentials during a variable demand spatial processing task. Aviation, Space, and Environmental Medicine, 65: 54-61.